QUIKSCAT BACKSCATTER SENSITIVITY TO LANDSCAPE FREEZE/THAW STATE OVER ALECTRA SITES IN ALASKA FROM 2000 TO 2007: APPLICATION TO SMAP VALIDATION PLANNING

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ABSTRACT

The mapping of freeze/thaw state of the landscape is one of the main objectives of NASA's upcoming SMAP (Soil Moisture Active and Passive) mission. This study applies ALECTRA (Alaska Ecological Transect) biophysical network and QuikSCAT scatterometer data to evaluate some of the validation issues regarding the SMAP freeze/thaw measurements. Although the QuikSCAT data is at Ku-band frequency, rather than the L-band of the SMAP instrument, the data is utilized due to its uniquely high temporal resolution over the ALECTRA sites. The results show that multiple temperature measurements representative of individual landscape (soil, snow cover, vegetation and atmosphere) elements and spatial heterogeneity within the satellite field-of-view are important for understanding the radar backscatter process and aggregate freeze/thaw signal. The backscatter temporal dynamics and relative contribution of these landscape elements to the freeze-thaw signal varies with land cover type, seasonal weather and climate conditions.

Index Terms* — *Freeze/thaw state, SMAP, QuikSCAT, ALECTRA

1. INTRODUCTION

The NASA Soil Moisture Active and Passive (SMAP) mission is dedicated to measurement of global soil moisture and boreal land surface freeze/thaw state [1]. The satellite will carry radar (active) and radiometer (passive) L-band instruments that will perform simultaneous and coincident measurements of the Earth's surface. The combination of data from the two instruments will allow unprecedented spatial accuracy and temporal frequency for global mapping of soil moisture and freeze/thaw state. The freeze/thaw state will be determined for boreal regions (>45°N) at minimum spatial classification accuracy of 80 % with 2-3 day repeat and 3 km spatial resolution.

The objective of the SMAP Science Cal/Val Program is to calibrate and validate the science algorithms and products relative to the mission requirements. The overall strategy to meet this objective in terms of Level 2 products (soil moisture and freeze/thaw state) includes (1) ground-based efforts: in situ monitoring using ground based observation networks and intensive field campaigns using airborne sensors and ground-data acquisition; (2) alternative satellite based soil moisture and freeze/thaw products, and (3) application of land surface modeling. This study contributes to the efforts establishing the ground-based validation strategy for the freeze/thaw state product.

In order to study the freeze/thaw state of the landscape and its relationship to radar backscatter the thermal conditions of each component of the landscape needs to be known. This requires a sophisticated data set. The Alaska Ecological Transect (ALECTRA) monitoring sites provide a unique data set that satisfies this requirement (see Figure 1). These sites are designed to capture spatial heterogeneity in temperature conditions at the level landscape microclimatic variability and encompass several measurements of the physical temperatures of the landscape from subsurface soil to vegetation stem and branches. Additionally, the sites observe plant growth activity through xylem sap flow measurements. Furthermore, many of the sites are situated in the vicinity of other experimental research sites including flux towers and other biophysical sampling stations. The sites investigated here are distributed along a north-south latitudinal transect across Alaska extending from Arctic coastal and upland tundra to interior boreal forest and maritime forest. These sites span a wide range of land cover, climate, topographic and vegetation conditions.

Numerous studies have established the application of radar backscatter time series for detecting the freeze/thaw state of the landscape (e.g. [2]- [5]). These studies encompass analyses utilizing L-, C-, and Ku-band frequency data. Since the objective of this study is to analyze the validation issues of SMAP measurements, the optimal frequency of choice would naturally be L-band.

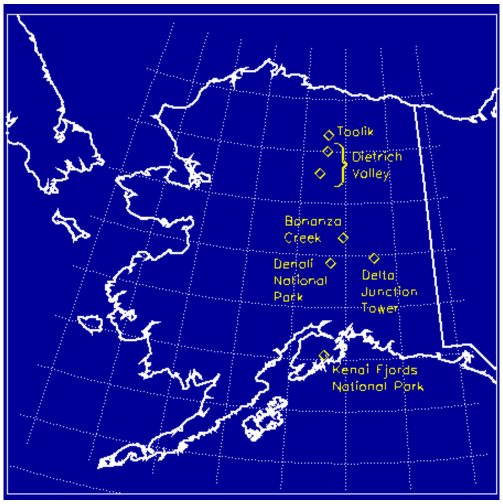

Figure 1. The location of most of the ALECTRA (Alaska Ecological Transect) stations. There new installations also at Franklin Bluffs (coastal tundra) and Sagwon (upland tundra).

However, there is no long time series of adequately high temporal fidelity (daily) radar measurements at L-band available over freezing and thawing areas. Therefore, the daily (applies over Alaska) Ku-band data of NASA's QuikSCAT satellite scatterometer obtained between years 2000 to 2007 is utilized. The effect of the vegetation is very different for Ku-band than for L-band; this is accounted for when interpreting the results. Furthermore, the analysis needs to account for the fact that QuikSCAT data has approximate 25 km spatial resolution (as opposed to 3 km for SMAP), which amounts to higher sub-grid scale heterogeneity within the sensor footprint. Both ascending (6 am) and descending (6 pm) overpasses of QuikSCAT are investigated with horizontally and vertically polarized backscatter.

2. DATA PROCESSING

This section describes the processing steps and main characteristics of ALECTRA and QuikSCAT data.

2.1. ALECTRA

Each subsite of ALECTRA stations provides coincident and co-located measurements of surface air temperatures, soil profile temperatures and vegetation stem and branch temperatures of locally dominant vegetation types. The analysis includes seven ALECTRA stations: A01 and A09 are located in the Bonanza Creek Experimental Forest representing White and Black Spruce, Balsam Poplar and Alder vegetation types; A04 is located in the Kenai Peninsula and is composed of Spruce, Poplar and Alder tree species; A05 and A06 are located in Denali National Park and represent open shrubland, White Spruce and mixed Spruce/Hardwood forest types; A07 and A08 are located in the Dietrich Valley and are composed of White and Black Spruce and shrubland types. Each station also accounts for varying local topological conditions.

The temperature measurements are first quality checked and erroneous data e.g. from failing sensors are flagged and eliminated. At each subsite there are several canopy measurements which are averaged as representative stem and branch temperature values. Figure 2 shows the time series of the aggregated temperature measurement points for station A01 subsite 1. The daily minimum, maximum and mean of each measurement point is then determined. Also, the measurement value at the time of the overpass is extracted for further analysis. For evaluating which temperature sensors are most important for the changes in the radar backscatter the binary state for each sensor were retrieved: the output of each sensor was reduced to give indication whether it was above or below a 0°C freeze/thaw temperature threshold. The processing produces five sets of data that can be directly compared with the processed QuikSCAT data.

2.2. QuikSCAT

The calibrated and DEM corrected QuikSCAT data is gridded to a polar EASE grid equal-area projection format.

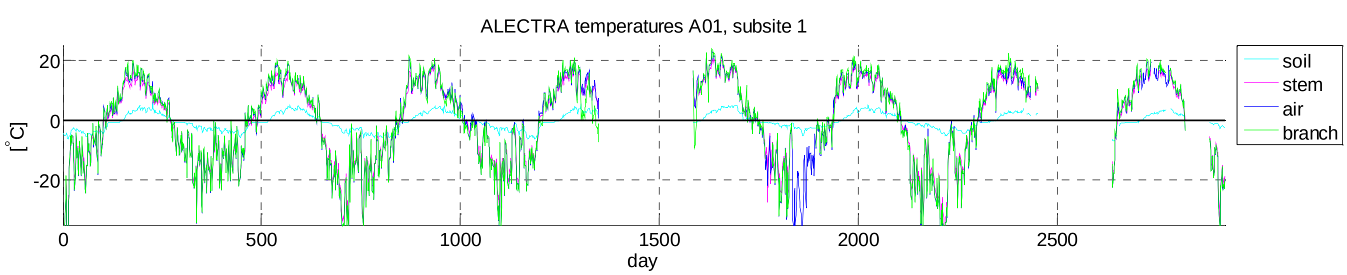

Figure 2. A sample of ALECTRA data for station A01 (Bonanza Creek) subsite 1 for years 2000-2007. The gaps in the plot are missing data due to logger or sensor issues.

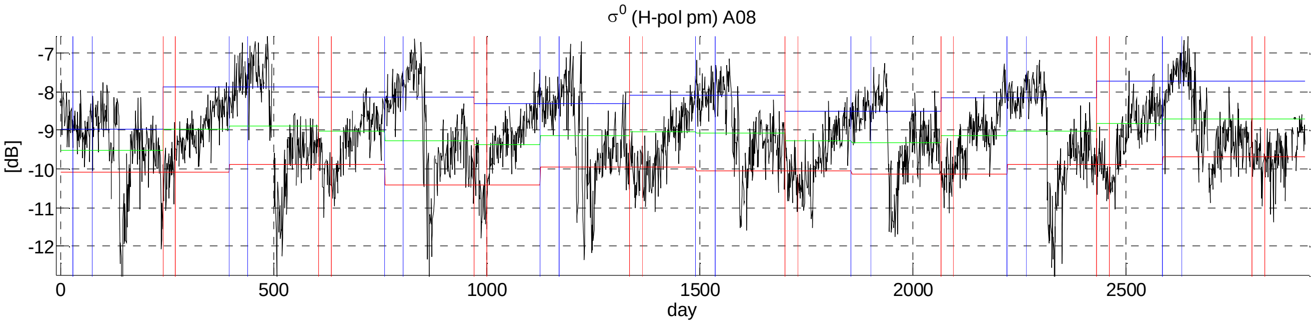

Figure 3. QuikSCAT HH-polarization PM-overpass backscatter over ALECTRA station A08 (Dietrich Valley) with frozen (blue) and thawed (red) condition reference points and the threshold level (green) for years 2000-2007.

The analysis is then focused on those grid points where the ALECTRA stations reside, resulting in seven data sets for both HH and VV polarized backscatter and AM and PM overpasses. A winter and summer reference level is determined from data obtained in January and September which offer stable thawed and frozen conditions over all stations (with slight exception regarding A04 station on Kenai Peninsula which experiences some thawing events throughout the winter season). A threshold level is then computed for all data as the average of the adjacent frozen and thawed references. Figure 3 shows the reference levels and resulting threshold for station A08 in Dietrich Valley. Additionally, the data obtained during July and August is removed, since the backscatter tends to increase during those months although the landscape conditions remain thawed.

In general, the signature over each ALECTRA station shows clear similarity for backscatter signature over the annual cycle (as can be seen in Figure 3 for A08). The maximum deviation from the mean of each day is only about 1 dB on average. On the other hand, the signatures are different from site to site and also the mean yearly freezing and thawing dates are notably different. This is due to different terrain, vegetation, snow cover and meteorological conditions. Hence, for example, the effect of snow cover and snow wetness on the backscatter at these extremes is very different which affects especially the detection of thaw events using Ku-band scatterometry.

3. RESULTS

The match between radar backscatter temporal changes and the binary freeze/thaw state of different landscape temperature elements was investigated by determining how much the backscatter obtained under frozen conditions overlap with the backscatter obtained under thawed conditions. The reason for this approach is that in this way the backscatter freeze/thaw algorithm of choice does not affect the result, and using only the binary state of the landscape temperature element does not overemphasize the magnitude of the temperature. Figure 4 shows the normalized distribution of the positive and negative temperatures with respect to the backscatter difference from the threshold level for station A08 subsite 4. A benchmark value is computed from this plot: the number of occurrences on the wrong side of the backscatter difference is divided by the total number of occurrences. This value is used to estimate how well the changes in the backscatter correspond to each temperature measurement.

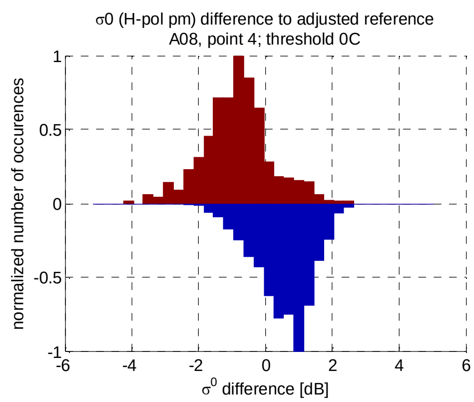

Figure 4. The histogram showing the normalized distribution (y-axis) of positive (red) and negative (blue) temperatures versus the backscatter difference (x-axis) from the threshold level.

Table 1 summarizes the benchmark values for H-polarization QuikSCAT data for PM overpass for all stations and their and subsites. The table includes air, stem and branch measurement points. The soil temperature is measured at the sites but for the Ku-band backscatter its correspondence did not seem to be very strong. The temperature data is selected based on the equatorial overpass time i.e. 18:00. The light green cells in the table show the best performance within a subsite and darker green cells show the best performance for the whole station. Table 1 also shows the predominant vegetation type of each subsite. In most cases the best result is achieved from the temperature measured either from the stem or branches of the canopy.

Additionally, an overall benchmark is calculated: this is the mean of the lowest values of each subsite (i.e. the light green values in Table 1). Table 2 shows the overall benchmark value for AM and PM overpasses for both horizontally and vertically polarized data for each ALECTRA data set (daily mean, min, max, 06:00 and 18:00). The backscatter obtained from the AM overpasses seems to yield the best result when compared to daily mean temperatures.

Table 1. The benchmarks for air, vegetation stem and branch temperatures (light green shows the best performance within subsite and darker green shows the best performance within the whole station): QuikSCAT H-polarization AM-overpass versus mean daily temperature from the ALECTRA stations

ST.	SUB	AIR	ST	BR	Type
A01	1	0.20	0.19	0.22	W. Spruce
	2	0.21	0.21	-	B. Spruce
	3	-	0.21	-	Poplar
	4	0.24	0.23	0.22	Alder Shrub
A04	1	0.21	0.18	0.18	Sitka Spruce/Poplar
	2	0.20	0.16	0.18	Alder
A05	1	0.25	0.23	-	Open Shrub (Willow)
	2	0.22	0.23	0.24	W. Spruce
A06	1	0.26	0.26	0.26	W. Spruce/Balsam Poplar
A07	1	0.23	0.22	0.29	B. Spruce bog
	2	0.22	0.23	0.20	B. Spruce, north slope
	3	0.22	0.23	0.21	W. Spruce, south slope
	4	0.23	0.23	0.21	Open Shrub/Bog (Willow)
A08	1	0.23	0.23	0.23	W. Spruce
	2	0.23	0.26	0.22	Open Shrub
	3	0.25	0.23	0.25	Open Shrub, sloped (Willow)
	4	0.22	0.24	0.20	Open Shrub, Sandy soil
A09	1	0.22	0.20	-	Birch, south slope
	2	0.19	0.20	-	B. Spruce/Larch bog
	3	0.20	0.21	-	W. Spruce, hill base

Table 2. Overall benchmark for the data sets. The best combinations are marked with green color.

	Max	Min	Mean	1800	0600
H-pol PM	0.22	0.26	0.22	0.22	0.26
H-pol AM	0.22	0.22	0.21	0.22	0.22
V-pol PM	0.23	0.28	0.23	0.23	0.27
V-pol AM	0.23	0.23	0.21	0.22	0.22

4. CONCLUSIONS

The backscatter data from the QuikSCAT scatterometer was analyzed against the landscape temperature record obtained from the ALECTRA biophysical network. The analysis is applied for the planning of the validation of the freeze/thaw product of the SMAP mission. The results indicate which thermal sensors in the landscape predict most accurately the Ku-band scatterometer response to freezing and thawing. The results vary with terrain and land cover conditions, which could mean that different validation strategies for different landscapes are called for. In most cases the canopy temperature had the best correspondence to backscatter changes.

The results are obtained in this study using Ku-band frequency backscatter at 25-km resolution. However, as the SMAP mission will be making measurements at L-band and higher resolution certain aspects of the results need to be considered. The penetration depth of L-band makes it likely that soil temperature will have a larger effect on the radar backscatter response. Also, as the landcover heterogeneity of the northern landscape is very high the 25-km footprint aggregates areas which will be seen separately at 3-km with unique response. Therefore a closer look at the division of the ALECTRA stations into subsites is required before far reaching conclusions can be drawn on which type of landscape requires which measurements.

The long time series in general shows high consistency of the response from year to year. The data set will allow detailed day-to-day investigation of numerous freezing and thawing events to understand the landscape response. The analysis can then be combined with L-band observations over the sites with less temporal fidelity, which will contribute to the formulation of the correct in situ sampling strategy for SMAP validation.

ACKNOWLEDGMENT

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REFERENCES

[1] Soil Moisture Active and Passive Mission, http://smap.jpl.nasa.gov, Jet Propulsion Laboratory, California Institute of Technology.

[2] McDonald, K., J. Kimball, R. Zimmermann, J. Way, S. Frolking, S. Running, "Application of Spaceborne Scatterometer for Mapping Freeze-Thaw State in Northern Landscapes as a Measure of Ecological and Hydrological Processes", IGARSS'99, pp. 2121-2123, 1999.

[3] Running, S., J. Way, K. McDonald, J. Kimball, S. Frolking, A. Keyser, R. Zimmermann, "Radar Remote Sensing Proposed for Monitoring Freeze-Thaw Transitions in Boreal Regions", EOS, American Geophysical Union, Vol. 80, No. 19, May 11, 1999

[4] Chapman, B., K. McDonald, G. McGarragh, C. Williams, "JERS-1 SAR Mosaics of the North American Boreal Forests", American Geophysical Union, Fall Meeting 2002

[5] Kimball, J.S., K.C. McDonald, S.W. Running, and S. Frolking, 2004. Satellite radar remote sensing of seasonal growing seasons for boreal and subalpine evergreen forests. *Remote Sensing of Environment* 90, 243-258.